the observed pressures at St. Louis were reduced to sea level, and the pressures at 10 kilometers were reduced to 15 kilometers on the days when there were no records at 15 kilometers, using for this purpose the mean observed difference in temperature between the two strata. The pressures at all other heights were derived from the records of the sounding balloons.

TABLE 1.—*Temperatures at different heights above sea level derived from records obtained with sounding balloons sent from St. Louis, Mo., 167 meters above sea level.*

Date.	Hour.	Height.	Temperature.	Date.	Hour.	Height.	Temperature.
1906.	P. M.	Meters.	°C.	1906.	P. M.	Meters.	°C.
April 28......	7:33	167	24.4	May 8........	7:05	167	10.1
	8:09	5,000	-8.8		7:33	5,000	-20.6
	8:52	10,000	-50.7		8:07	10,000	-47.5
29......	7:00	167	24.6	9.......	6:55	167	15.0
30.......	6:14	167	14.1		7:24	5,000	-14.6
	6:49	5,000	-3.8		8:04	10,000	-53.2
	7:33	10,000	-42.9		8:34	12,500	-53.7
	8:09	12,000	-55.6	10......	6:40	167	20.0
May 1......	6:40	167	26.7		7:09	5,000	-13.6
	7:22	5,000	-10.9		7:41	10,000	-51.4
2......	7:05	167	20.0		8:15	15,000	-58.1
	7:45	5,000	-11.9	11.......	7:00	167	27.1
	8:41	10,000	-48.0	12.......	6:33	167	23.9
3......	6:07	167	25.6		7:22	5,000	-5.5
	6:47	5,000	-10.5	13......	9:00	167	21.1
	7:50	10,000	-50.8		9:36	4,000	3.4
4......	8:46	167	17.2	14......	6:33	167	25.3
	9:03	5,000	-4.3		7:04	5,000	-6.9
	....	10,000	-37.8		7:37	10,000	-44.2
	....	13,000	-51.4		8:04	15,000	-58.0
5......	6:54	167	15.0	15.....	6:52	167	26.1
	7:26	5,000	-8.0	16.......	6:46	167	27.9
	8:02	10,000	-45.0		7:17	5,000	-2.5
	8:58	15,000	-54.2	17......	6:26	167	29.0
6.	6:50	167	13.4		7:02	5,000	-3.5
	7:23	5,000	-8.4	18......	6:19	167	23.2
	7:56	10,000	-47.0		6:50	3,500	5.8
	8:24	15,000	-51.7		A. M		
7......	7:14	167	16.1	19.......	5:36	167	20.0
	7:47	5,000	-13.2		6:18	5,000	-3.2
	8:22	10,000	-53.2				
	9:08	15,000	-55.0				

TABLE 2.—*Pressures at different heights above sea level derived from records obtained with sounding balloons sent from St. Louis, Mo., 167 meters above sea level.*

Date.	Pressure at sea level.	Pressure at 2 kilometers.	Pressure at 5 kilometers.	Pressure at 10 kilometers.	Pressure at 15 kilometers.
1906, 7 p. m.	mm.	mm.	mm.	mm.	mm.
April 28.....................	757	599	413	207	99
29.....................	761				
30.....................	763	602	416	211	101
May 1.....................	754*	599	412		
2....................	758	598	410	206	98
3.....................	754	598	411	205	98
4.....................	753*	595*	411	210	100
5.....................	760	597	410	206	98
6.....................	763	598	407	204	98
7.....................	764	601	411	205	97
8.....................	770†	601	406*	200*	93*
9.....................	769	604	410	202	93
10.....................	765	604	413	206	97
11.....................	763				
12.....................	763	605	418		
13.....................	763	605†	417		
14.....................	763	605	418	211	99
15.....................	763				
16.....................	762	605	418		
17.....................	761	605	419†		
18.....................	760	603	417		

* Minima.   † Maxima.

The pressures at different heights are plotted in Fig. 2. The maxima and minima in this figure are indicated by the letters *a*, *b*, *c*, etc. Comparing the maxima and minima at sea level and 5 kilometers the first maximum *a* occurs nearly simultaneously at the two levels, but after that the maxima in one level coincide with the minima in the other. This inversion is more marked at 10 kilometers where the pressure curve is almost the reverse of that at sea level. The pressure curve at 15 kilometers is somewhat similar to that at 10 kilometers, but the ranges are much reduced and the maxima and minima are evidently on the point of disappearing. In fact, in the interval from the 4th to the 8th, which was best covered by observations, the smaller fluctuations found at 5 to 10 kilometers do not occur at 15 kilometers. In the upper-air type of curve there is distinct evidence of lagging in the time of the most marked maxima and minima. The minima *c* and *g* and the maximum *d* evidently occur about twelve hours later at 10 to 15 kilometers than at 5 kilometers.

In order to ascertain at what level in the atmosphere the sea-level type of pressure changed to the upper-air type, the pressure for each day was obtained from the records for the height of 2 kilometers. These pressures are given in the third column of Table 2. The results show that the sea-level minimum of May 1 did not exist at 2 kilometers; but the minimum of May 4 was well defined at that level, altho with diminished range, and disappeared between 2 and 5 kilometers. The well-defined maximum at sea level on May 8 is not shown at 2 kilometers, and is replaced at 5 kilometers by a sharp minimum of pressure. These results indicate that the sea-level type of pressure does not extend to heights much exceeding 2 or 3 kilometers. This conclusion is sustained by the observations of clouds at Blue Hill, which show that the air ceases to rotate around centers of high and low pressure at heights of about 3 kilometers, and that above that height the motion is of an entirely different character, consisting only of deflections to the right and left in a general easterly drift.[4] When the pressures are charted synoptically, there are found at sea level elliptical isobars around which the wind circulates, going spirally inward or outward, according to whether the central pressure is lower or higher than that in surrounding regions. At about 3 kilometers this type changes suddenly to the upper-air type of pressure, in which the isobars are U-shaped or semi-circular, and not circles or ellipses as at the ground. The bottom of the U points southward when the pressure is below the normal, but is inverted (∩) and points northward when the pressure is above normal. In this type the line of minimum pressure is found near the place of minimum temperature, and many hundreds of miles distant from the minimum of pressure at the earth's surface. The line of maximum pressure is found near the place of maximum temperature, and far from the maximum pressure at the earth's surface. To some extent these facts were outlined by Doctor Köppen as long ago as 1888, when he first plotted isobars for the upper air; but it is not uncommon to find in the writings of meteorologists of to-day references to areas of high and low pressure as if they extended to great heights in the atmosphere. In future I think we must ascribe the unstable vertical gradients of temperature, which give rise to thunderstorms and tornadoes, not to the overflow of surface air by potentially cooler air above, but rather to the northward flow of relatively warm air at low levels, beneath currents moving from the west or northwest above, or to the heating of the ground and surface air by the sun.

My conclusion that cold waves are inclined strata of descending air felt first at the earth's surface and successively later at greater heights is given in the MONTHLY WEATHER REVIEW for March, 1907.[5] The reason of the later occurrence of warm waves aloft is no doubt because the areas of low pressure in the upper air are in the rear of areas of low pressure at sea level. The winds in front of these areas of low pressure in the upper air have a component of motion from the south and hence are relatively warm; while the winds immediately below, in the rear of the lows at sea level, have a component of motion from the north, forming the advancing lower front of the cold wave, and are relatively cold.

OUR PRESENT KNOWLEDGE REGARDING THE HEAT OF EVAPORATION OF WATER.

By Prof. ARTHUR WHITMORE SMITH, Ph. D. Dated University of Michigan, Ann Arbor, Mich., November 20, 1907.

Until quite recently our knowledge of the amount of heat required to evaporate water has been derived from the classic

[4] See Annals of the Astronomical Observatory of Harvard College, vol. XXX, 1896.

[5] Vol. XXXV, p. 118-120.

experiments of Regnault, and even to-day, in spite of half a dozen modern researches, his results are quoted and used by scientists generally more often than all the others combined. Most of Regnault's work dealt with high temperatures, and these results are still of undoubted value; but Regnault himself expresses doubt regarding the accuracy of his results at low temperatures. Nevertheless the confidence which is inspired and justified by the accuracy of his work at the higher temperatures is often extended to the entire range, without any examination of the original data. It is the object of this paper to set forth our present knowledge of the subject as shown by the most reliable investigations of recent years.

Dieterici.—Undoubtedly the best determination of the heat of evaporation of water at low temperatures is that of Dieterici.[1] In 1889 he evaporated water within a Bunsen ice calorimeter. The water was placed in a small bulb within the inner tube of the calorimeter, and after thermal equilibrium was fully established all the water was evaporated by means of reduced pressure—the heat required being furnished by the further freezing of the ice mantle. Assuming that one mean calorie will expel 0.01544 gram of mercury—this being the average of the values found by Bunsen, Schuller and Wartha, and Velten—he obtained[2] the value 596.80 mean calories for the heat of evaporation at 0° C. Eliminating this assumption, what he really determined in this investigation was that

$$.01544 \times 596.80 = 9.2146 \text{ grams of mercury}$$

were expelled from the ice calorimeter when one gram of water at 0° C. was evaporated into vapor at the same temperature.

Dieterici has recently calibrated his ice calorimeter in terms of the electrical units. A carefully measured electric current past thru a fine resistance coil within the inner bulb of the calorimeter. As the ice mantle melted, thus reducing its volume, mercury was drawn into the calorimeter, the exact amount being found by careful weighings. In a series of ten experiments[3] the total amount of heat supplied by the current was 3049.28 joules. The corresponding total amount of mercury drawn into the calorimeter was 11.2663 grams. The electrical units are exprest in terms of a Weston element, and probably the above result is exprest in Reichsanstalt joules. Since Reichsanstalt volts are larger than international volts by the factor 1.00081, and this factor enters twice in the formula *EIT* by which the electrical energy was computed, we have for the amount of heat corresponding to each gram of mercury drawn into the calorimeter

$$3049.28 \times (1.00081)^2 \div 11.2663 = 271.09$$

international joules per gram of mercury.

Combining this result with that of the earlier investigation gives at once for the heat required to evaporate one gram of water at 0° C.

$$9.2146 \times 271.09 = 2498.0 \text{ international joules.}$$

Dieterici has also made a direct calibration of his calorimeter in terms of "mean calories", that is, in terms of one-hundredth of the amount of heat that a gram of water gives out in cooling from 100° C. to 0° C. The water was inclosed in a small quartz tube, both tube and water being heated to about 100° C. and then dropt into the calorimeter. Correction was made for the heat carried by the quartz tube. The mean of 13 experiments gave 0.015491 gram of mercury per mean calorie.[4] This result is larger than other determinations of the same constant, and therefore must carry some doubt until corroborated by further reseaches. Using this value Dieterici finds 4.1925 for the mechanical equivalent of heat, which likewise is larger than the accepted value. Combining this result with his earlier ones gives

$$9.2146 \div 0.015491 = 594.83$$

mean calories per gram of water evaporated. But this result is not as reliable as the preceding one.

A. W. Smith.—Coming next in the order of ascending temperatures is the recent investigation, the full account of which I have given in a previous paper.[5] The method used was to draw a stream of dry air thru the water within a calorimeter, thus evaporating some of it. An unvarying electric current furnished heat in a form susceptible of precise measurement, while the stream of air was continually adjusted to evaporate just enough water to maintain a constant temperature. This air current, after leaving the calorimeter laden with water vapor, bubbled thru two baths of sulfuric acid in which it was reduced to the same degree of dryness that it possest just before it entered the calorimeter. Therefore whatever water it took from the calorimeter was left in the sulfuric acid, the amount being determined by careful weighings on a precision balance. Special pains were observed that no water could escape from the calorimeter in the form of spray or fine drops carried by the air current; and the air current, after leaving the calorimeter, past thru warmer tubes where it could not deposit any of the water it was carrying in the form of vapor.

This method possesses several advantages over others that might have been used. The water is slowly evaporated into air at nearly atmospheric pressure, so the method corresponds more nearly to natural evaporation than when the water boils under reduced pressure. Besides water does not boil easily or steadily at these low temperatures. But the principal advantage is that an experiment can be commenced or ended at any time without disturbing the set-up in the least, and one experiment can follow another with no interval between. When the calorimeter is holding a constant temperature, with the air current bringing away its steady stream of water vapor and the electric current supplying the equivalent amount of heat, an experiment, so-called, can be made at any time that is convenient. An experiment is really only a single determination of the *time rate* of this stream of vapor, and several such determinations can be made in one day. For this purpose the two sulfuric acid tubes are inserted in the outcoming air current for a measured interval of time. When these tubes are removed fresh ones are put in their place, and no vapor escapes unmeasured. Such a series of successive determinations is more valuable than the same number of experiments made at different times, because whatever thermal uncertainties may be left at the end of one run are carried forward to the next. For example, if some part of the calorimeter should be warmer at the close of an experiment than it was at the beginning, thereby holding heat which should have been used for the evaporation of water, and if during the next run, when equilibrium is attained, the extra evaporation makes the collected water too large, then the average of these two results will not only possess the usual weight of a mean, but it will be absolutely correct as regards this particular kind of uncertainty. It is for this reason that the experiments are made consecutive, one beginning where the other left off, until a set of four separate determinations has been made.

The energy supplied by the electric current was computed from the formula *EIT*. Both the current *I* and the fall of the potential *E* were measured in terms of a standard cadmium cell. The particular cell used was compared both before and after the experiments with the best cadmium cell in the laboratory, whose electro-motive force in terms of the Clark cell is very exactly known. Therefore all measurements are really based upon the electro-motive force of the Clark cell as set up according to the regular specifications, which is given as 1.434 international volts at 15° C. They are thus given in terms of a definite and reproducible unit. Should the electro-motive force of the Clark cell be found to be less than this

[1] Ann. der Phys., vol. 37, p. 494–508, 1889.   [2] Ibid., p. 504.
[3] Ann. der Phys., vol. 16, p. 614, 1905.
[4] Ann. der Phys., vol. 16, p. 603, 1905.
[5] Physical Review, vol. 25, p. 145–170, 1907.

value by 1 part in 1000, all of these results will be decreased by 2 parts in 1000. They will then be exprest in terms of the new unit as exactly as they are now given in international joules.

The results obtained are given in the accompanying Table 1, which is self-explanatory. The second column gives the temperature of the evaporating water. The weight of water evaporated is given in the third column, the observed weight being corrected for the buoyancy of the air. This buoyancy is less than it would be for the same amount of water by itself, inasmuch as the volume of the mixture of water and acid is less than the sum of their separate volumes. The exact density of the mixture was obtained from the latest tables of Landolt and Börnstein, and the corresponding correction applied to determine the true weight of the water *in vacuo*. I is the current thru the heating coil, E the fall of potential between its terminals, and L denotes the electrical energy expended for the evaporation of each gram of water.

TABLE 1.—*Collected data, giving the results obtained in each experiment.*

Date.	Water evaporated.		Duration.	Assuming $E_{15}=1.43400$ volts.		$L=\dfrac{EIT}{W}$
	Temperature.	Amount (reduced to vacuum).		E	I	
1907.	° C.	Grams.	Seconds.	Volts.	Amperes.	Joules.
February 7.	21.18	3.0651	7197	3.7609	.27725	2448.4
	21.19	3.0585	7197	3.7618	.27735	2455.1
	21.18	3.0723	7197	3.7621	.27747	2445.4
February 8.	21.16	3.0586	7197	3.7610	.27725	2453.6
	21.16	3.0743	7197	3.7617	.27721	2441.2
	21.16	3.0640	7197	3.7613	.27729	2449.9
	21.16	3.0595	7197	3.7614	.27721	2452.8
February 9.	21.20	3.0595	7197	3.7617	.27725	2453.4
	21.20	3.0644	7197	3.7613	.27725	2449.2
	21.20	3.0598	7197	3.7613	.27721	2452.5
March 9....	21.14	2.7827	7197	2.1514	.43997	2448.1
	21.15	1.9024	5908	2.0737	.43998	2445.0
March 16...	13.96	1.8581	7203	2.9000	.21998	2473.0
	13.95	2.1754	8404	2.9000	.21999	2464.6
	13.95	1.7885	6903	2.9001	.22000	2462.6
	13.95	1.9438	7504	2.9001	.22002	2463.3
March 23...	28.06	3.1023	7205	3.8118	.27503	2434.8
	28.06	3.1314	7265	3.8117	.27503	2432.2
	28.06	2.3032	5344	3.8119	.27504	2432.6
	28.06	2.3264	5403	3.8118	.27504	2434.9
April 6.....	39.80	3.2481	7202	3.9468	.27499	2406.6
	39.80	3.2548	7203	3.9470	.27500	2402.2

The mean value of the electrical energy required for the evaporation of one gram of water at each temperature is:

Temperature.	Heat of evaporation.
° C	Joules.
13.95	2465.9
21.17	2449.5
28.06·	2433.6
39.80	2404.4

Altho only two values were obtained on March 9, yet these are especially valuable, as the calorimeter used on that date was one of the earlier forms. The resistance of the heating coil was much less, thus requiring a larger current than on other days. These two determinations are, therefore, free from any constant bias due to the particular form of calorimeter used. It will be noticed, however, that the results agree very closely with the others obtained at the same temperature.

Griffiths.—Some years ago Griffiths made an elaborate investigation[6] into the heat of evaporation of water. His original intention was to cover the range from 10° C. to 60° C., but only a few results at 30° C. and at 40° C. are given, and he says: "Had time permitted I should have performed more experiments, especially at 30° C.". His preliminary method was to draw dry air thru the water, but this failed to give

concordant results, and the final determinations were made by the more common method of reduced pressure.

A weighed amount of water was placed in a glass tube within the calorimeter, and flowed out thru a fine opening as fast as it was evaporated. Heat was supplied by an electric current which was stopt, as nearly as possible, when the last of the water was evaporated. The experiments were conducted at a constant temperature and appear to have been very carefully performed. The heat furnished by the current was computed from the formula $H = E^2 T/R$, the value of E being measured in terms of a Clark cell the electro-motive force of which was taken as 1.4342 volts at 15° C. He exprest his results in calories, using 4.199 for the mechanical equivalent of heat. Using the same factor to translate the results back into joules gives

2429.3 joules at 30.00° C., and
2403.6 joules at 40.15° C.,

when exprest in terms of 1.43400 volts for the Clark cell at 15° C.

Henning.—About a year ago there appeared[7] the account of an investigation for the range from 50° C. to 100° C. A few determinations were made at 30° C., but for some reason are given only one-eighth the weighting accorded to the determinations at each of the higher temperatures. The water was made to boil under reduced pressure, the vapor being condensed and weighed. Heat was supplied by an electric current and measured in terms of a Weston standard cell. Probably the results were obtained in terms of Reichsanstalt volts. They are exprest in 15° calories by means of the factor 4.188 joules per calorie. I have reduced them back to international joules by multiplying by this same factor and also by 1.0016.

Whether exprest in calories or joules, most of Henning's results appear rather high. This is very apparent at 100° C., where the familiar number 537 is exceeded by nearly two units. However, Henning is not alone in finding this larger value, and it may be that the accepted value is too low. Certain it is that this important constant should be redetermined with modern appliances and with a greater degree of precision than has yet been done.

Regnault.—In 1847 Regnault made a series of 23 experiments at temperatures between 63° C. and 88° C. Steam from his boiler, at somewhat reduced pressure, was condensed within a calorimeter, the heat given out being determined by measuring the rise in temperature of the calorimeter bath. The unit in which the results are exprest is determined by the range of temperature of the water in the calorimeter. In every experiment this was nearly the 15-degree calorie, and, therefore, not far from the mean calorie. As there is some question whether Regnault's temperatures were measured on the mercurial or the nitrogen scale, and, therefore, whether his results should be corrected for the varying specific heat of the water in his calorimeter, it seems best to record his results as he gave them—especially as the corrections, if applied, would alter the final result by less than one-tenth of one per cent.

Results at 100° C.—By far the greater number of experiments have been made with water boiling under atmospheric pressure. Regnault conducted a series of 44 experiments under varying conditions and with different calorimeters, obtaining results which are entirely concordant and the accuracy of which can hardly be questioned. Since "Regnault's calorie" is very nearly equal to the mean calorie his final result is practically exprest in mean calories.

Thirty years later, in 1877, Berthelot[8] devised a calorimeter for studying the heat of evaporation of liquids at their boiling points. The accuracy of the apparatus was tested by using water, which gave 635.2, 636.2, and 637.2 in three trials. The

[6] Phil. Trans., vol. 186 A, p. 261–342, 1895.

[7] Ann. der Phys., vol. 21, p. 849–878, 1906.
[8] Ann. Chem. et Phys., vol. 12, p. 558, 1877.

mean is 636.2 calories for the "total heat", or 536.2 for the heat of evaporation of water.

In a similar way, Louguinine[9], in 1896, devised an elaborate apparatus for use with other liquids, and tested it by using water. Four experiments gave 637.87, 635.59, 637.64, 638.53 with a mean of 637.26 calories. The temperatures are not given, but corresponding values computed from Regnault's formula give a mean of 637.0 calories.

At the end of Griffiths's paper is a short note by Joly[10] in which he gives the results of 10 experiments with the steam calorimeter. 12.8545 grams of water were warmed from 11.89° C. to 99.96° C. by the condensation of 2.0994 grams of steam. Using Regnault's value, $L=536.66$, for the heat obtained from each gram of this steam he finds for the mean specific heat of water over this range (12° to 100°) the value 0.99520. From the observations of Bartoli and Stracciati this number should be 0.9995, and from the curve of specific heat as determined by Barnes it is 0.99938. In order to have obtained these values Joly would have had to use $L=538.98$ and $L=538.90$ mean calories, respectively.

As noted above the results obtained by Henning are also high, being 538.9 mean calories at 100° C.

In view of such varying results it is extremely difficult to determine the most probable value for the heat of evaporation at 100° C. Apparently it is not below 537 or above 539, but even this is uncertain, and a more careful determination may show that it lies outside these limits. For the present, however, a mean value, 538, best represents this important constant.

Determinations above 100° C.—The only work above the boiling point is that of Regnault, who carefully investigated the range 119° C to 195° C. Indeed it is this portion of his work in which he felt the greatest confidence and from which he deduced the well-known formula, $L=606.5+.305\,t$. In all 73 experiments were made, and these have been collected into 12 groups for the purpose of appearing clearly on the curve of Fig. 1, where only the mean value of each group is shown. Since the value at 100° C. has been taken at 538, the portion of the curve for higher temperatures is steeper than the above equation would show. There is no reason why the two portions of the curve should not be continuous in the region of 100° C. and thus form one smooth curve thruout their entire length, but from these observations it can not be so drawn unless the work of Henning is to be entirely disregarded, and that of Regnault from 60° C. to 200° C. accepted with entire confidence. An accurate and reliable determination at 100° C. would thus determine the location of this curve for a considerable range on either side.

According to Callendar, Preston, and others, the heat of evaporation becomes zero at the critical temperature, which Cailletet and Colardeau found[11] to be 365° C. This would require a very sharp downward turn of the curve beyond the observations of Regnault. The exact location of the curve above 200° C. is, however, mere conjecture.

In the accompanying Table 2 are collected the results of these various investigations. The third column shows the average temperature at which the water was evaporated. The heat of evaporation, as reported by the authors themselves, is given in the next column. These values are not directly comparable, inasmuch as they are exprest in different kinds of "calories". In those experiments where the heat was supplied by means of an electric current I have computed the result in international joules, taking the legally authorized value of 1.434 volts for the electro-motive force of the Clark

[9] Ann. Chem. et Phys., vol. 7, p. 251–252, 1896.
[10] Phil. Trans., vol. 186A, p. 322, 1895.
[11] Comptes Rendus, t 112, p. 563, 1891.
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cell at 15° C. Since the actual value of the electro-motive force of a Clark cell at this temperature is, in all probability, nearer 1.433 volts, the results are reduced to this unit also. The values obtained by Regnault and by Joly are exprest directly in mean calories and require no further correction.

TABLE 2.—*Collected results of all investigators.*

Observer.	Number of experiments.	Temperature (Centigrade).	Result as reported.	Joules per gram.		Mean calories.
				$E=1.434$	$E=1.433$	
Dieterici	20	0.00	596.80	2498.0	2494.6	596.28
A. W. Smith	4	13.95	....	2465.9	2462.5	588.61
	12	21.17	....	2449.5	2446.1	584.69
	4	28.06	....	2433.6	2430.2	580.89
	2	39.80	....	2404.4	2401.0	573.91
Griffiths	7	30.00	578.70	2429.3	2425.9	579.86
	6	40.15	572.60	2403.6	2400.2	573.72
Henning	8	49.14	569.55	2389.0	2385.6	570.23
	6	64.85	559.47	2346.8	2343.4	560.14
	13	77.34	552.47	2317.4	2314.0	553.11
	24	89.29	545.76	2289.3	2285.9	546.40
	18	100.59	538.25	2257.8	2254.4	538.87
Regnault	8	68.0	556.4	....	....	556.4
	8	79.9	549.0	....	....	549.0
	7	85.8	544.8	....	....	544.8
	44	99.88	536.7	....	....	536.7
Joly	10	99.96	....	....	....	538.9
Regnault	3	120.3	521.7	....	....	521.7
	4	126.8	517.6	....	....	517.6
	11	135.9	511.9	....	....	511.9
	13	145.2	504.9	....	....	504.9
	10	155.5	495.7	....	....	495.7
	5	162.4	491.5	....	....	491.5
	14	175.2	482.3	....	....	482.3
	9	185.6	478.1	....	....	478.1
	4	194.6	471.0	....	....	471.0
Cailletet	....	365.	....	....	....	(zero)

The mechanical equivalent of heat.—When it comes to translating the results here collected from the electrical units, "joules", into heat units, "calories", it is necessary to use the constant known as the mechanical equivalent of heat. And since the specific heat of water is not constant, but has a different value for each temperature, it is necessary to define precisely what is meant by the term "calorie". The unit used in this paper is the "mean calorie", that is, one per cent of the heat that is required to warm one gram of pure water from 0° C. to 100° C.

The mechanical equivalent of heat has been determined by several investigators. The classic experiment of Joule paved the way for the more precise measurements of Rowland, who worked on a larger scale and used an engine to stir the water in his calorimeter, thereby warming it more rapidly. This investigation was conducted with masterly precision and gives one of the best determinations of the mechanical equivalent over the range 5° C. to 35° C.

More recently Reynolds and Moorby[12] have directly measured the amount of mechanical work required to warm pure water from the freezing to the boiling point. The care and precaution observed in their work, and the minute discussion of possible sources of error, warrant unusual confidence in their result. Ice-cooled water was past in a continuous stream thru a hydraulic brake dynamometer consisting of a central disk carrying vanes on each side and running between similar stationary vanes. The terrific stirring experienced by this water warms it, and by properly regulating the rate of flow it could be made to leave the brake at any desired temperature. In these experiments a single brake absorbed the power of three large engines, and the flow of water was regulated to leave the brake at very nearly 212° F. and under sufficient pressure to prevent the formation of steam. The measured amount of heat is thus independent of all thermometric scales, thermometers being used only to identify the freezing and boiling

[12] Phil. Trans., vol. 190A, p. 300–422, 1897.

points. In order to eliminate constant errors as far as possible, a set of experiments of one hour each in which small power was employed was followed by a similar set in which two or three times as much power was used. Since the temperatures, speeds, etc., were the same for each set many uncertainties would be the same in each case. Therefore, the final result is computed considering only the *difference* in the works and the *difference* in the heats in the two cases. Every possible source of error was carefully examined, the weighings were reduced to vacuum, and account taken of the air dissolved in the water.

Exprest in absolute units, the work required to warm one gram of water from the freezing to the boiling point was found to be 4.1832×10^7 ergs, or 4.1832 joules, per degree centigrade. Inasmuch as this covered nearly the entire range of temperature from 0° C. to 100° C. no correction was required for the varying specific heat of water. But an examination of the details of the experiments shows that the mean range of temperature was from about 1° C. to 100° C., and according to Barnes the average specific heat from 1° C. to 100° C. is less than that from 0° C. to 100° C. by 1 part in 10,000. Applying this slight correction gives for the mechanical equivalent of a mean calorie, the value

$$J = 4.1836 \text{ joules.}$$

Another method of determining this constant is to warm the water by means of an electric current. The principal investigations are those of Griffiths, Schuster and Gannon, and Callendar and Barnes. In the first two investigations water was warmed in a calorimeter. In the work of Callendar and Barnes everything was maintained at a constant temperature, a steady electric current in a platinum wire warming a continuous stream of water. The electrical energy was determined by measuring the current and the fall of potential over the wire, each in terms of a standard Clark cell. The results as first reported by these physicists were somewhat too large, owing to the fact that the electro-motive force of their Clark cell was taken as 1.4342 volts at 15° C. In a critical discussion of this entire subject before the International Electrical Congress at St. Louis in 1904, Professor Barnes[13] gives the results as recalculated on the basis of 1.43325 volts at 15° C. for the Clark cell. I have plotted Barnes's values from 0° C. to 100° C. and very carefully integrated the resulting curve in order to determine the mean value over this range of temperature. The result gives 4.1846 joules per mean calorie, which is slightly smaller than the arithmetical mean of the 21 values given by Barnes, inasmuch as in the arithmetical mean the first and last values receive twice the weight given to intermediate values.

At the present time the most probable value for the electro-motive force of a Clark cell at 15° C. is 1.433 volts. This means that the above result should be still further reduced, even in the ratio of $(1.43325)^2$ to $(1.43300)^2$, since the electrical energy was computed by the formula EIT, and both E and I were measured in terms of the Clark cell. Making this correction gives

$$J = 4.1846 \times \frac{(1.43300)^2}{(1.43325)^2} = 4.1832 \text{ joules.}$$

Rowland, by the mechanical method, and Griffiths and Schuster and Gannon, by the electrical method, found slightly larger values than this. The reason for any discrepancy has not yet been explained, but is usually considered due to the different methods of calorimetry. Inasmuch as Reynolds and Moorby and Callendar and Barnes both used the "continuous method", in which there is no change of temperature in any part of the apparatus while the heat is carried away in a continuous stream of water, it would seem as tho their results would be the more directly comparable. And since I have

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[13] Trans. Int. Elec. Congress, 1904, vol. I, p. 65.

used a similar method and have avoided all changes in temperature, the most applicable value of J is that determined by Reynolds and Moorby, *provided* the electro-motive force of the Clark cell at 15° C. is taken as 1.433 volts. The values in the first half of the last column, "mean calories", of Table 2 are computed by means of the factor, $J = 4.1836$.

The results of all these investigations were carefully plotted on a sheet of accurately engraved cross-section paper, and the smooth curve which most nearly represents all the values was drawn. (See fig. 1.) From the curve were then determined the values of the heat of evaporation for each five-degree point from 0° C. to 100° C. and for each ten-degree point from 100° C. to 200° C.
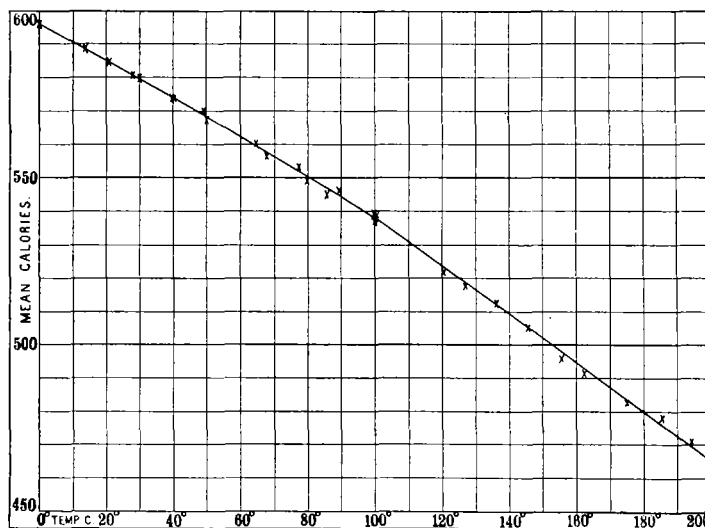

FIG. 1.—Heat of evaporation of water at different temperatures.

TABLE 3.—*Heat of evaporation of water.*

Temperature.	Heat required to evaporate one gram.		
	Joules.	Mean calories.	20°-calories.
° C.	$E=1.4330$	$J=4.1836$	$J=4.1773$
0	2494.6	596.3	597.2
5	2483.4	593.6	594.5
10	2472.1	590.9	591.8
15	2460.4	588.1	589.0
20	2448.7	585.3	586.2
25	2437.0	582.5	583.4
30	2425.2	579.7	580.6
35	2413.5	576.9	577.8
40	2401.4	574.0	574.9
45	2389.3	571.1	572.0
50	2377.1	568.2	569.1
55	2365.0	565.3	566.2
60	2352.4	562.3	563.2
65	2339.9	559.3	560.2
70	2327.3	556.3	557.1
75	2314.8	553.3	554.1
80	2302.2	550.3	551.1
85	2289.7	547.3	548.1
90	2277.1	544.3	545.1
95	2264.2	541.2	542.0
100	2250.8	538.0	538.8
110	2220.7	530.8	531.6
120	2190.1	523.5	524.3
130	2159.6	516.2	517.0
140	2129.5	509.0	509.8
150	2099.3	501.8	502.6
160	2069.2	494.6	495.3
170	2038.7	487.3	488.0
180	2008.5	480.1	480.8
190	1978.4	472.9	473.6
200	1948.3	465.7	466.4
365	Heat of evaporation vanishes.		

While it is possible to write the equation of this curve, such a formula would be of doubtful value. It is better to show the actual curve and the points among which it is drawn, for this will be less likely to give the appearance of unwarranted accuracy or completeness. Above 100° C. we have only the work of Regnault, performed sixty years ago. At 100° C. are several points, differing by more than seems

necessary, and there is also a sharp bend in the curve at this point. The lower part of the curve seems to be very definitely determined, and below 50° C. there is unanimous agreement among the various investigators.

Calorimetric investigations are frequently conducted at room temperatures and the results exprest in terms of the "calorie at 20° C.". For this reason the values in the last column of Table 3 are given. They are computed from the values in the preceding column by means of the factor $\frac{4.1846}{4.1783}$, obtained from the variation curve of Barnes. The 15-degree calorie may be taken as equal to the mean calorie.

If the finally accepted value for the Clark cell at 15° C. is not 1.433 volts, then a new calculation of the above values from the data in the original papers will be in order. But until this point is definitely settled, these values are the best available for all those who have occasion to use the heat of evaporation of water, either by itself or as a correction factor in other investigations.

INTERESTING OLD METEOROLOGICAL LITERATURE.

The Meteorological Library of the Johns Hopkins University desires to secure as complete a set as possible of the early publications of our various State weather service organizations. Before the present systematic uniformity was introduced by Professor Moore these State publications were of various sizes, shapes, and styles; and many of them were personal matters by our local observers, encouraged by General Greely and Professors Harrington and Moore as leading up to State organizations. Any one who has either whole sets or odd numbers of these old monthly sheets that he will present to the above-mentioned meteorological library should mail them to Dr. Nicholas Murray, Librarian, Baltimore, Md.

The pioneers in these personal enterprises were (1) Kerkam and Hunt, at New Orleans, La., 1891 and 1892; (2) Moore, at Milwaukee, Wis., 1892; (3) Hunt, at Omaha, Nebr., 1893–94; (4) Beals, at Minneapolis, Minn.; (5) Hunt, at Atlanta, Ga., 1894–95; and the publications for these years would be of great historical interest. Besides these publications by Signal Service men personally, we may also note those of an official character by the State weather services established about 1885 and subsequently.

FIRE AT MOUNT WEATHER.

About 4 a. m. on the morning of Wednesday, October 23, 1907, fire was discovered in the administration building at Mount Weather. Altho it had already gained much headway, the occupants escaped with little difficulty, except one who sustained severe injuries by jumping from a window. It was useless to try to check the flames and there was time to save no Government property and scarcely any private belongings. The building was totally destroyed, causing a loss of about $25,000 to the Government on building, furnishings, instruments, etc., and about $6,500 to the occupants.

All books and records in the building were destroyed, including the only copies of the regular meteorological records from the first of the month, and some records of special investigations which had not been copied or worked up for publication, and which are therefore completely and irreparably lost. The loss in the way of instruments is far less serious; for the exposed thermometers, thermograph, and gages, tho near the building, were unharmed; and the equipment for upper air research and the valuable instruments for investigations in terrestrial magnetism and solar radiation were in distant buildings and therefore unaffected.

Altho several of the men were compelled to borrow clothing from their more fortunate comrades and from neighbors, yet the daily work of kite flying and observations was immediately resumed on the day of the fire, and has suffered no interruption. A meteorological observatory has been temporarily installed in the power house, and telegraphic communication with Bluemont and Washington was speedily restored.

ICE COLUMNS IN GRAVELLY SOIL.

We have lately learned that a very important article on this subject was published a few years ago, in the Japanese language, and we shall endeavor to obtain a translation or abstract thereof. Meantime those interested in the subject will perhaps be glad to add the following title to the bibliography of the subject.

Report of investigation of ice columns by Prof. M. Goto, Higher Normal School, Tokyo, Japan, and Prof. O. Inagaki, Higher Agricultural School, Morioka, Japan. In the "Toyo Gakugei Zasshi" (Oriental Science Monthly), Vol. 16, 1900, Nos. 211, 212, and 213; 38 pages; 12 experiments.

This memoir contains:

Chapter I. Introduction.
 II. Facts known to previous investigators.
 III. Facts made known by our investigations.
  i. Reasons why ice columns grow upward.
  ii. Upward pressure of the growing ice columns.
  iii. The morphology of the ice columns.
   a. Forms of ice columns.
   b. Density of ice columns.
   c. Specific gravity of ice columns.
   d. Limit of growth of ice columns.
   e. Damage done by these ice columns.
   f. Relations of soils and the growth of ice columns.

PLEASE ANSWER THESE QUERIES PROMPTLY.

The Editor has been asked to what extent he can diminish the size of the MONTHLY WEATHER REVIEW, and how he can improve its value to its readers. Considered as a meteorological journal it must necessarily contain a wide range of material. It is consulted by teachers, engineers, climatologists, and special students of a variety of topics, and the Editor wishes to submit to these the question what can be done to remove unnecessary material and improve the general value of the publication.

Will not each reader, whether domestic or foreign, kindly consider the following questions as addrest to him personally, and reply by return mail to the Editor?

(A) Are the following features of so much interest to you as to be worth publishing, either for your own personal use or in the general interest of meteorology?

1. The chapter on forecasts and warnings.
2. The section on rivers and floods.
3. The special articles, notes and extracts.
 a. Popular.
 b. Educational.
 c. Technical.
 d. Bibliographical.
 e. Seismological.
4. The chapter on "The weather of the month".
5. The climatological summary.
6. Table I.   Climatological data.
7. Table II.   Climatological record.
8. Table III.   Wind resultants.
9. Table IV.   Excessive precipitation.
10. Table V.   Canadian data.
11. Table VI.   Heights of rivers.
12. Honolulu data.
13. Jamaica rainfall.
14. Chart I.   Hydrographs for seven principal rivers.
15. Chart II.   Paths of areas of high pressure.
16. Chart III.   Paths of areas of low pressure.
17. Chart IV.   Total precipitation.
18. Chart V.   Daytime cloudiness.
19. Chart VI.   Isobars and isotherms at sea level and resultant surface winds.
20. Chart VII.   Total depth of snowfall.
21. Chart VIII.   Amount of snow on ground.